Explora Inc.

Traditional and Artificial Intelligence based techniques to measure trees: an overview.

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Abstract

To address the problem of climate changes, CO_2 sequestration by forests should be assessed. Forests store carbon in their biomass- about half of it is carbon. The trees' diameter, height and age are relevant parameters for forests' biomass estimation.

Various methods have been utilized to estimate forests' biomass. Initially, field measurements using tape measures, clinometers and frequently a ruler were used. They are precise but limited to local scales. In contrast, remote sensing, like drones and satellites, can provide images at regional and global scales. They can use optical, radar or Light Detection and Ranging (LiDAR) sensors for this purpose.

LiDAR is more accurate than optical or radar sensors. It is becoming incorporated in smartphones such as I-Phone 12. Mixed-reality devices also have emerged to involve people in forests mapping, in addition to existing tree measuring apps.

Google Earth provides free and historical data, but does not offer hypespectral images required to properly estimate biomass.

Drones perform three-dimensional terrain geometry, which is relevant to determine trees' height. They are widely available today.

Carbon captured by forests (and for other land use types) can be used to compensate forest growers and farmers, as they are contributing to mitigate climate change.

Keywords: forests' biomass; remote sensing; satellites; Google Earth; drones; LiDAR; carbon offsets

1. Introduction

Forests uptake approximately 45% of the terrestrial Carbon (Bonan, 2008). The Carbon Dioxide captured, through photosynthesis, is stored in trees in the form of Aboveground Biomass (AGB) (Rodríguez-Veiga et al., 2017). Through that process, they also release Oxygen into the Atmosphere (Rodríguez-Veiga et al., 2017). In fact, about 50% of the biomass of the trees is carbon (Zolkos et al., 2013), so forests help to balance the carbon cycle (Laosuwan & Uttaruk, 2014). Therefore, mapping forest biomass globally and its change over time is needed to estimate carbon sequestration and monitor deforestation (Koch, 2010).

Traditionally, ABG have been measured in the field using hand-held equipment, that have high accuracy (Hyde et al., 2006). However, field-based methods are time-consuming and are normally limited in scope to only sampling at the landscape scale (Hyde et al., 2006). In contrast, remote sensing usage for forest properties estimation capture satellite images across large areas, even at the global scale (Rodríguez-Veiga et al., 2017). Nevertheless, remote sensing estimates should not have errors higher than 20% in relation to field estimates (Zolkos et al., 2013). They are completely autonomous and deliver transparent data (Ojjeh, 2022).

The new types of remote sensing data include full wave laser scanning, polarimetric radar interferometry and hyperspectral data (Koch, 2010). Sensors could be mounted on satellites, ground-based platforms, and aerial platforms, which include aircraft or unmanned aerial vehicles (UAVs), like drones (Sishodia et al., 2020).

Remote sensing systems generate a large volume of data due to their high spectral, spatial, temporal, and radiometric resolutions (Sishodia et al., 2020). Spatial resolution of a sensor corresponds to the size of the pixel that represents the area on the ground (Sishodia et al., 2020). Sensors with high spatial resolution tend to have small footprints (Sishodia et al., 2020). In fact, footprint is defined by the area illuminated by sensor pulse, which depends on the distance from the target (Rosette et al., 2012). Spectral resolution of a sensor is indicated by the number of bands captured in the given range of electromagnetic spectrum (Sishodia et al., 2020). Hyperspectral images contain a great number of contagious bands of narrow width separated by small increments in wavelength (Sishodia et al., 2020).

Remote sensing systems can be passive or active (Zolkos et al., 2013). Passive remote sensors include Landsat, AVIRIS, QuickBird, and MODIS (Zolkos et al., 2013). Active sensors include LiDAR (Light Detection and Ranging) and Synthetic Aperture Radar (SAR) (Zolkos et al., 2013).

Passive remote sensors measure different wavelengths of reflected solar radiation (Zolkos et al., 2013). They provide two-dimensional information that can be used to calculate vegetation cover fraction and indices like Normalized Distance Vegetation Index (NDVI) (Rosette et al., 2012). In fact, remote sensing is also capable of made deforestation risk estimations (Ojjeh, 2022), and fractional cover (FC) can be one of the pointers of forest degradation (Laosuwan & Uttaruk, 2014). The spatial resolution of passive optical systems varies by sensor, from ~2 m in QuickBird to 250 m in MODIS (Zolkos et al., 2013).

Active sensors emit energy capable of penetrating through forest canopies to the Earth's ground surface (Zolkos et al., 2013). SAR have high spatial resolution, situated between about 25 to 100 meters, and emit microwave wavelength (Zolkos et al., 2013). LiDAR systems emit at wavelengths between 900 and 1064 nm (Zolkos et al., 2013). It registers the return time during between the emission of laser pulse, its reflectance on the target and its return to the sensor (Zolkos et al., 2013). This time interval permits the calculation of the distance between the tree and the device which contains the sensor (Zolkos et al., 2013). Therefore, LiDAR is a valuable technology due to the directness of its approach to measuring canopy structure. It also has high accuracy (Zolkos et al., 2013).

LiDAR performance varies between and within forest types (Zolkos et al., 2013). This is attributed to allometric equations it uses to estimate biomass, stem density, canopy volume, height, and wood specific gravities (Zolkos et al., 2013). Therefore, it is possible to have similar forest structure but differing density of trees (Zolkos et al., 2013). There are five main types of forests, like boreal, tropical, temperate deciduous, temperate conifers and temperate mixed (Zolkos et al., 2013). In general LiDAR models' performances are poorer in boreal and temperate deciduous than in tropical forests (Zolkos et al., 2013).

LiDAR models are normally better than radar and optical models at estimating Aboveground Biomass (Zolkos et al., 2013). In fact, performance errors of radar and optical models are in general significantly higher than LiDAR errors (Zolkos et al., 2013). However, optical sensors have a large board-scale horizontal mapping vegetation structure capabilities, and SAR and LiDAR are better in vertical mapping (Hyde et al., 2006). That is why many studies have been proving that the combined use of the different types of sensors results in more accurate biomass estimations (Koch, 2010).

1.1. Landsat and Sentinel usage for forest biomass estimations

The Landsat satellites were developed by NASA to allow governments to meet programmatic needs like spatial planning (Wulder et al., 2019). Indeed, free and open access to archival and new imagery has resulted in a myriad of innovative applications and novel scientific insights (Wulder et al., 2019).

Landsats 1 to 3 have Multispectral Systems with bands that occupied visible and near infrared wavelengths (Wulder et al., 2019). Landsat 4 and Landsat 5 have 30 m of spatial resolution (Wulder et al., 2019). The Landsat-7 has an additional 15-m spatial resolution panchromatic channel in relation to 4 and 5 (Wulder et al., 2019). Landsat 8 is doted by a Thermal Sensor and an improved image acquisition rate of about 700 scenes/day (Wulder et al., 2019). Landsat 9 possess a Thermal Sensor with better calibration than the Landsat 8's Thermal Sensor (Wulder et al., 2019). Landsat 10 is an enhancement of Landsat 9 with new compact image technologies, international partnerships, and involvement in commercial sector (Wulder et al., 2019).

The Sentinels satellites were developed by the Copernicus European Space Agency's program to permit European Commission develop environmental policies (Butler, 2014). In fact, Sentinels are very valuable due to diverse measurements of the major components of Earth systems they assess (Butler, 2014).

Sentinel 1 provides weekly frequency radar images, and it is sensitive to the phenology dynamics of deciduous forests (Wang et al., 2019). It has a two-satellite constellation, i.e., Sentinel 1-A, launched in 2014, and Sentinel 1-B, launched in 2016 (Wang et al., 2019). They can continuously image cloudy areas (Butler, 2014). Sentinels 2 to 5 use optical sensors, spectrometers, and radiometers to measure everything (Butler, 2014). Sentinel 2 has, like the first appearing, a two-satellite constellation: Sentinel 2-A, launched in 2015, and Sentinel 2-B, launched in 2017 (Wang et al., 2019). Sentinel 6 will again use radar altimeters (Butler, 2014).

Many studies, like one performed by Astola et al. (2019), have reported better performance of Sentinel 2 data as compared to Landsat 8 data. The latter has lower spatial resolution and lower image acquisition frequency than the former (Astola et al., 2019). However, Landsat series are also operational and enable advanced monitoring of forest and land covering (Astola et al., 2019).

1.2. Drones Usage in Forestry Remote Sensing

Use of drones in forest management (Kameyama & Sugiura, 2020) and land use mapping has emerged in the last decade (Sishodia et al., 2020). To reconstruct a forest on a MultiView Geometry from video-based drone imagery it is important to consider flight altitude, image resolution and overlap (Kameyama & Sugiura, 2020). Use of drone images may help assess the impacts of existing forestry policies and management practices at national scales (Sishodia et al., 2020). Basic data related to estimates of tree height and volume measured with drones is required for verification of its accuracy (Kameyama & Sugiura, 2020). Kameyama & Sugiura (2020) conclude that there is a positive correlation between canopy area and Diameter at Breast Height (DBH) determination.

The flight altitude of the UAV must be 150 m above ground level or lower (Kameyama & Sugiura, 2020). In fact, it is necessary for the flight altitude to be low and the degree of overlap in photography to be high (Kameyama & Sugiura, 2020). Although flight altitude doesn't influence so much volume estimations, low flight altitude conditions have smaller errors in estimation of tree's height than high altitudes (Kameyama & Sugiura, 2020). However, to set the flight altitude it is important to consider the terrain of the takeoff site, landing site, and flight area (Kameyama & Sugiura, 2020).

In summary, there are some advantages of using UAV as forestry remote sensing (Kameyama & Sugiura, 2020). Among them, it could be highlighted their versatility, cost-effectiveness, safety, flexibility in shooting and hight density data with resolution at cm-scale (Kameyama & Sugiura, 2020).

2. Aim of the project

The main objective of this study is to compare multiple forms of measuring trees. In Section 4 it is presented traditional methods used by forest farmers to determine trees' height and diameter. In Section 5 it is explained the importance of determining trees' age and a formula to calculate it. In Sections 6 to 8 it is shown various comparisons between the own existing remote sensing methods. In 9 it is given a little explanation of what are carbon offsets.

3. Forest Biomass Estimation using Remote Sensing Direct and Indirect (or inferring) methods.

Estimations of forests' biomass using remote sensing can be effectuated by direct or indirect manners (Kosh, 2010).

Direct estimations of biomass are made determining the relationships between biomass and the signal responses registered by the remote sensing device utilized (Kosh, 2010). This relationship could be evaluated using statistical ensemble methods, multiple regression analyses or neural networks (Kosh, 2010).

Indirect estimation implies the creation of models that relate response of the variable of interest and remotely sensed auxiliary variables at two times (Mc Roberts et al., 2015). Then, it is estimated the changes as the differences in the model predictions for the two times (Mc Roberts et al., 2015). Remote sensing indirect methods are based in estimates of trees height, crown closure and tree or forest type (Kosh, 2010).

4. Calculating trees' biomass in a traditional manner

4.1. Measuring trees' height

Traditional methods of measuring tree height include field measurements and a hand-held clinometer, hypsometer, or measurement pole can be necessary (Enterkine et al., 2022). A tape measure is also fundamental in field works.

4.1.1. Measuring trees' height on a flat plan

To measure a tree on field, person should move far away from it until a point where even has a great view of crown (Commonwealth of Massachusetts, 2023). Then, he should use the clinometer to determine the angle between eye's level and the top of the tree (Commonwealth of Massachusetts, 2023). Using a measuring tape, the operator should measure the horizontal distance from his location to the trunk of the tree (Commonwealth of Massachusetts, 2023). To calculate the height, user will need a scientific calculator to find the tangent of the angle, in degrees, reading from the clinometer (Commonwealth of Massachusetts, 2023).

The height since eye's level is determined how it is shown in Equation 1. Therefore, to determine total tree's height, person's height should be added to the result obtained from Equation 1.

$Height = \tan(clinometer's\ angle) \times distance\ to\ trunk$ (Commonwealth of Massachusetts, 2023).

Equation 1: Determining tree's height since person's eyes level.

4.1.2. Measuring trees' height on a sloping ground

In a slop plan, the clinometer must be used to firstly determine the angle between tree's base and observer's eyes level (Department of Environment and Climate Change, 2007). Then, it must be used to measure the angle between person's eyes level and tree's crown (Department of Environment and Climate Change, 2007).

4.1.2.1. The base of the tree is below eyes' level.

To better understand this point, let's take look in Figure 1. Being AD the distance between tree's trunk, D, and person's eyes level, A, and α the angle between horizontal and top, BD is calculated how Equation 2 shows:

$BD = \tan\alpha \cdot AD$ (Larjavaara & Muller-Landau, 2013)

Equation 2: Calculation of the distance BD

The tree's height is done by BD + CD (Larjavaara & Muller-Landau, 2013). Analogously to BD, and being β the angle between eyes' level and tree's base, CD can be calculated how is shown in Equation 3:

$CD = AD \cdot \tan(\beta)$ (Larjavaara & Muller-Landau, 2013)

Equation 3: Calculation of the distance CD

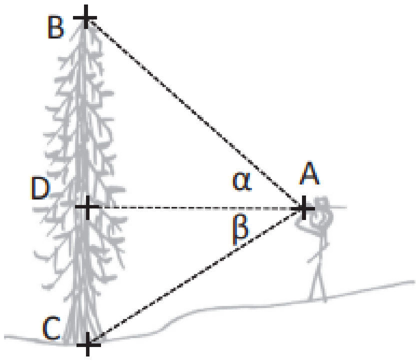

Figure 1: Parameters to the determination of a tree's height in a slope ground. Source: Larjavaara & Muller-Landau, 2013

4.1.2.2. The base of the tree is above eyes' level.

Figure 2 explains how to calculate tree's height when tree's base is above person's eyes level. Note that A_2 is the angle between tree's base and the horizontal.

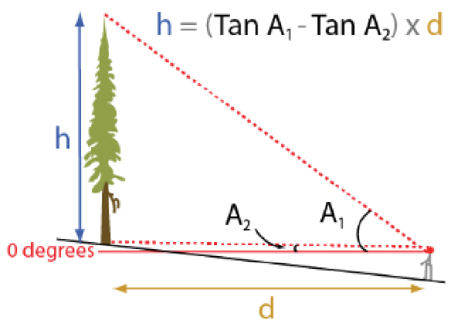

Figure 2: Measuring a tree when its base is above observer eyes' level. Source: BC Big Tree, 2019

4.2. Determining trees' circumference

Tree circumference is easiest to measure with a flexible tape measure (Commonwealth of Massachusetts, 2023). However, a string can be used to mark the circumference and then measured with rigid tape measure or a ruler (Commonwealth of Massachusetts, 2023). People that are measuring must wrap the tape measure around the girth of the tree (Commonwealth of Massachusetts, 2023). They must try to keep the tape 90 degrees to the natural lean of the tree, how it is shown in Figure 3.

The circumference must be measured at a certain height on the trunk (Commonwealth of Massachusetts, 2023). If it is being made a measure in Europe, Canada or Australia, this must be effectuated at 1.3 metres above ground level (Abdurrazaque, 2022). In Korea and Japan, this measure should be done 1.2 meters tall (Abdurrazaque, 2022). In New Zealand, at 1.4 m, and in United States, at 1.37 meters (Abdurrazaque, 2022).

Figure 3: Measuring tree's perimeter. Source: Commonwealth of Massachusetts, 2023

With the determination of tree's perimeter, it is possible to get diameter dividing circumference value to the mathematic constant π (Abdurrazaque, 2022).

5. Determination of tree's age: another important parameter to estimate forests AGB.

Trees have different growth rates. Their growth rates are of considering importance because faster growing plants had higher survival rates (O'Brien et al., 1995). In fact, allometric biomass equations of individual aboveground tree components are age specific (Peichl & Arain, 2007).

Ages for a given diameter can be estimated by calculating time required to grow through each doubling size class from size class specific growth rates (O'Brien et al., 1995). Age can be correlated with height to estimate the length of time required by different species to reach the canopy of a forest (O'Brien et al., 1995).

Biomass and Carbon stock estimates for aboveground biomass are derived from forest inventory data by applying allometric biomass equations and biomass expansion factors (BEFs) (Peichl & Arain, 2007). It is important to refer that BEFs play a fundamental role in trees' biomass estimations (Peichl & Arain, 2007).

It is known that allocation of biomass to individual tree components changes over the forest's life cycle (Peichl & Arain, 2007). Applying allometric equations without considering age may lead to significantly over or underestimation of trees' components biomass (Peichl & Arain, 2007).

The trees' diameter (DBH) is important to estimate its size, volume, growth and calculate its potential value as a source of wood (Abdurrazaque, 2023). Besides this, the probability of mortality decreases approximately of an exponential form with increasing diameter growth rate (O'Brien et al., 1995).

The age of a tree could be calculated using the Expression in Equation 4:

$$Age\ (years) = BEF \times DBH\ (inches) \qquad \text{(Abdurrazaque, 2023)}$$

Equation 4: Determination of a tree's age

where BEF is determined how is represented in Equation 5:

$$BEF_i = \frac{W_i}{V} \qquad \text{(Peichl \& Arain, 2007).}$$

Equation 5: BEF calculation

where i corresponds to each tree component (branch, leaves), W_i is biomass (tons) of a component and V is the stem volume, in m^3 (Peichl & Arain, 2007).

6. Artificial Intelligence Based Applications and Devices to measure trees

6.1. Mixed reality devices

There are head-mounted mixed-reality devices, like Microsoft HoloLens, that can be used to quantify plant species and visualize changes in vegetation structure (Gorczynski & Beaudrot, 2022). Inexpensive, it is equipped with depth sensors and scanners that detect, identify and map tree positions in the surrounding world, overlaid with virtual projections (Evans et al., 2017). This device is advantageous permitting to user save more time (Evans et al., 2017) while interact simultaneously with an immersive space and the real world (Gorczynski & Beaudrot, 2022).

6.2. Smartphone and tablet applications and conjugation with remote sensing data

6.2.1. LiDAR sensors in recent iPhones and iPads

Since 2020, it is disponible LiDAR sensors in Apple's iPhone and iPAD models (Tatsumi et al., 2022) to generate three-dimensional understorey data (Mokroš et al., 2021). Such devices are iPAD PRO 2020, iPAD PRO 2021, iPhone 12 PRO, iPhone 12 Pro Max, iPhone 13 Pro and iPhone 13 Pro Max (Tatsumi et al., 2022). This sensor has a significantly high trees detection rate, whereby data is captured of a simple, rapid, and cheaper manner (Mokroš et al., 2021). This innovation permitted increase the accessibility of LiDAR technologies to non-experts (Tatsumi et al., 2022).

The Lidar sensor can be used in Applications available on Apple App Store destinated to these devices, like the free app Forest Scanner (Tatsumi et al., 2022). The maximum scanning distance of the sensor is 5 m, and its accuracy is high (Tatsumi et al., 2022). With the development of internal models and add-on hardware, i.e., Lidar units, the utility of such apps is expected to grow (Tatsumi et al., 2022).

6.2.2. Drones and phone applications

Drones can be used in conjugation with Smartphone trees' measurement applications. For instance, the phone app KATAM Forest scans tree density and trunk diameter (Katam technologies AB, 2022). This app gives only 30 days of free measurements. The app connects to a drone and put it flying, too (Precise Route Planning Tool, n.d.). Then it is possible to download maps, Orthophotos of high resolution generated by the drone and export and share the data (Precise Route Planning Tool, n.d.). This version of the app directly connected to a drone is KATAM Tree Map (Precise Route Planning Tool, n.d.).

6.2.3. Some Android and iOS applications

The 9 most common apps destinated for Android and ioS are Arboreal, Measure Height, Telemeter, Trees, Tree Meter, Tree Height Measurement, ImageMeter, Height Measure and AR Ruler App (Team, 2022). They use sensors like accelerometers and hygrometers and some of them is based in Augmented Reality (AR) (Team, 2022). The camera of the smartphone is crucial (Team, 2022).

6.2.3.1. Arboreal

Arboreal application allows the measurement of the height of everything, with focus in that of trees (Team, 2022). It uses AR and the user only must hold smartphone in vertical and point to the base and the top of the tree (Team, 2022). It realizes measures in feet or in meters, and its mode of functioning are shown in Figure 4. Note it is a paying app, with only 5 measurements free (Team, 2022).

Figure 4: Arboreal AR-based application to measure trees height. Source: Team, 2022

6.2.3.2. Telemeter

Using a camera device, its objective is to measure height of trees and their distance to the user of the app (Team, 2022). The position of the smartphone is indicated by the usage-guide provided by the application. The app can be calibrated with an object of known height (Team, 2022). Application works with sensors to be more accurate (Team, 2022). However, this app has the disadvantage of requiring payment to be installed and the payment for all the "Measurement tools" available in it. In Figure 5 is demonstrated one step of the application.

Figure 5: Telemeter trees distance and heigh calculator. Source: Team, 2022

6.2.3.3. Trees

Point to the top of a tree with your phone camera and insert the distance you are to the tree (Team, 2022). The name and the diameter of the tree are also inputs to the calculation of tree height by the app. Measure diameter with a tape measure and a ruler (Team, 2022). The application requires localization of the user, and diameter measured must be inserted (Team, 2022). User must point first to the top and then to the roots (Team, 2022). In Figure 6 is shown a part of its functioning mode.

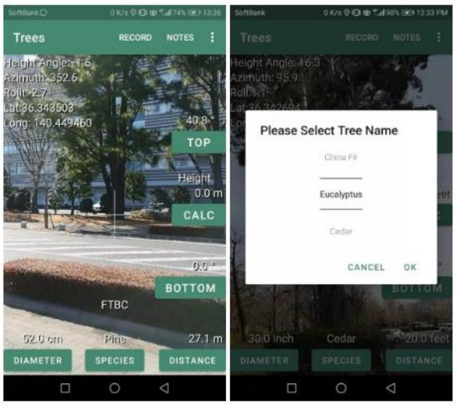

Figure 6: Trees phone app functioning mode. Source: Team, 2022

6.2.3.4. Measure height (by Deskis OÜ)

Measure height app doesn't use AR but calculate the approximate value of tree's height through trigonometric equations (Team, 2022). If user marks where tree begins and where it ends, it calculates the distance to the tree and phone angle (Team, 2022). Figure 7 shows its interface.

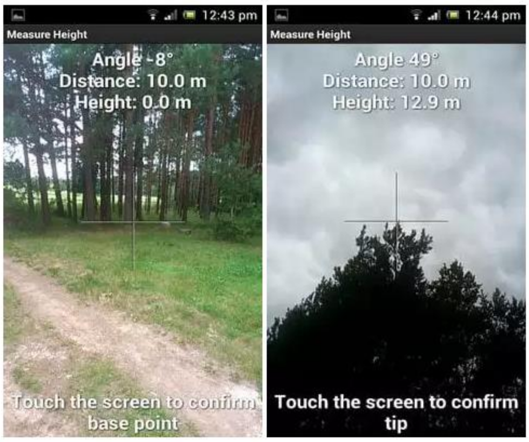

Figure 7: Measure Height app. Source: Team, 2022

6.2.3.5. Tree meter (by Inalbyss Technologies)

If user have a reference object of known height, he must put it next to the tree at its right (Team, 2022). User must point to it with phone camera to avoid calculating the distance between himself and the tree (Team, 2022). The reference object can be another person, how is shown in Figure 8. Importantly, this is an app that you pay to install but requires no further payment for it to work properly.

It is the most intuitive and accurate app together with the app Trees, despite Trees is a little difficult in diameter determinations.

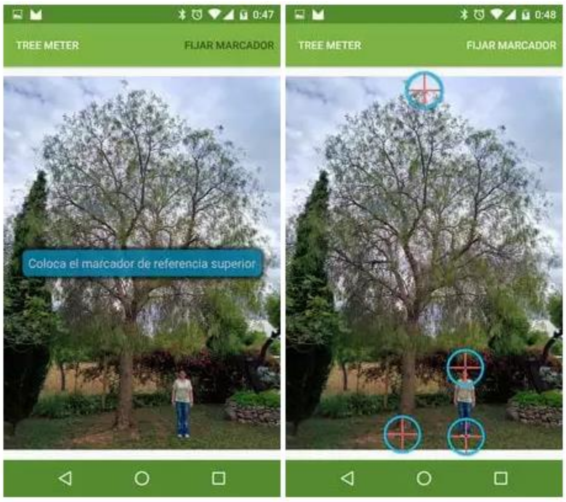

Figure 8: Tree meter application, available in English and Spanish. Source: Team, 2022

6.2.3.6. Tree Height Measurement

This app gives to the user rapid measurements of trees' height, and its interface seems old to not distract to this purpose (Team, 2022). It has two methods available for this calculation, from which user must choose one (Team, 2022). User guide is situated at the right of main screen, how Figure 9 represents.

Figure 9: Tree Height Measurement app interface. Source: Team, 2022

6.2.3.7. ImageMeter

This app uses photos to measure height or the length of everything there represented (Team, 2022). This is advantageous because user don’t have to realize any measure by his own and he can get the result in some instant. The app also can utilize user’s phone camera if a reference object is used (Team, 2022). Figure 10 shows the app’s interface with a photo of a house uploaded, but it could be a photo of a tree. However, it is not a very intuitive app in usage.

Figure 10: ImageMeter interface. Source: Team, 2022

6.2.3.8. Height Measure (by Hyreface)

It is a very simple and intuitive application that uses trigonometric equations to measure tree’s (or anything’s) height. The app calculates the distance between user and the tree if user points the camera to the base of the tree. It is represented in Figure 11 one part of its functioning mode.

Figure 11: Height Measure app. Source: Team, 2022

6.2.3.9. AR Ruler App

It is a clear app which works with AR technology and user must measure three times and use the average value. If the object captured is not a tree, user can also get other parameters, like area or volume. This app is shown in Figure 12.

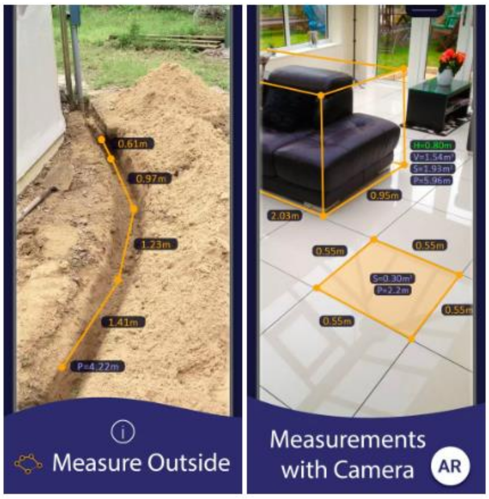

Figure 12: AR Ruler app interface. Source: Team, 2022

6.3. The Globe Observer NASA's App and validation of remote sensing data: the importance of public's measurements

With the creation of Global Learning and Observations to Benefit the Environment (GLOBE) program, NASA had the objective of engage people in measuring trees (Enterkine et al., 2022). A conjunction of the data collected by people over the World have been used to NASA's scientists to validate satellite trees' height measurements (Blumberg, 2019). The app GLOBE Observer is also adequate for other mobile devices besides smartphone (Enterkine et al., 2022) and requires a GPS connection to locate the tree (Blumberg, 2019).

The insertion of soil humidity conditions and the specie of the tree is important (Enterkine et al., 2022). It is essential to point phone's camera in such a way that it would be easy to clearly identify trees' base and top (Enterkine et al., 2022).

It is required to app utilizer hold the phone at eye level (Enterkine et al., 2022). User must tilt it between the bottom and the crown to capture the best angle[2], measured by the phone's internal gyroscope (Enterkine et al., 2022). To application estimate the distance, user should walk to tree's base in a straight line and count the number of steps (GLOBE Observer, n.d.). If the user is on a steep slope, the person should utilise a tape measure to register the exact distance to the tree (GLOBE Observer, n.d.). To estimate the tree's height, the application will use the angle and the value of the distance (GLOBE Observer, n.d.).

7. Google Earth pros and cons in forestry biomass estimations

Using very high-resolution (VHR) Quickbird or IKONOS data, with pixel size inferior or equal to 1 m^2, in forest biomass estimations is expensive (Ploton et al., 2012). In fact, this images costs makes their utilization sometimes prohibitive in describing forests canopy changes over time (Barrier et al., 2010). Hence, Google Earth software has emerging as an alternative free solution to monitor forest biomass and canopy size variabilities (Barrier et al., 2010). With cloud-based Google Earth Engine (GEE) platform, several series of Landsat images can be accessed, analysed, and processed in an automated manner (Alencar et al., 2020).

Landsat sensors has moderate spatial resolution (about 30 m), but they can store historical data measurements, which is important to monitor forest temporal dynamics (Alencar et al., 2020). Therefore, Google Earth images are of slightly lower quality in relation to VHR commercial optical data (Barrier et al., 2010). However, their reliability is sufficient to derive consistent characterizations of forest biomass and canopy textures (Barrier et al., 2010). It analyses in an intensive manner the focus areas desired by the utilizer by using magnified imageries (Um, 2021).

Google Earth's images don't have saturation problems above biomass values as high as 500 Mg/ha (Ploton et al., 2012). It has also the capacity to differentiate visually between forest and non-forest areas, giving a perception of soil using types (Um, 2021). However, it hasn't the capacity to test and detect forests' structural changes along time series (Hamunyela et al., 2020). So, many authors, like Hamunyela et al. (2020), have

[2] https://youtu.be/NFP7eXC3Ku0

been implemented this functionality through algorithms like Breaks for Additive Season and Trend monitor. This offers approaches for testing and detecting structural breaks in time series considered from user (Hamunyela et al., 2020). A positive break over a forest area means a cover's increase, and a negative break is related to forest abnormal changes (Hamunyela et al., 2020).

There are various possible algorithms to ABG estimation based on Google Earth Engine (Yang et al., 2018). Nonetheless, they utilize very complex equations, especially for small (pixel or area) scales, how Yang et al. (2018) shows in their study. This even may compromise the ability for widespread use of Google Earth for forest biomass estimates.

8. Comparison between satellite remote sensing and eBee Drones for forestry biomass estimations. It makes sense using eBee drones' cameras?

Radar systems can collect Earth feature data irrespective of weather or light conditions (Lu, 2006). However, data saturation problem is common in radar data (Lu, 2006). In fact, saturation levels depend on wavelengths and the characteristics of vegetation stand structure and ground conditions (Lu, 2006). Therefore, one possibility to reduce data saturation problem is to use narrow-wavelength images (Lu, 2006).

Using longer wavelength radar data is not always feasible since most longer wavelength satellites are commercial satellites, whose data is expensive (Li et al., 2020). Hyperspectral and LiDAR sensors are also costly, difficult to pre-process, and require expert knowledge in their images analysis (Oldeland et al., 2017). Therefore, usage of 3D data derived from images captured using drones has shown great potential in reducing costs and improving forest biomass estimations (Kachamba et al., 2016).

UAVs are advantageous over satellite and airborne data due to their extremely flexible in usage (Oldeland et al., 2017). In addition, they easily carried to diverse locations and flights can be scheduled in a very short time interval, for instance, daily or weekly (Oldeland et al., 2017). UAVs can also be equipped with sensors like RGB and Near-Infrared (NIR) spectral bands (Sharma et al., 2022). For all these reasons, application of UAVs in monitoring forest ecosystems and in biomass estimation is gaining increased attention (Kachamba et al., 2016).

eBee drones can capture areas of 1 km^2 during a single flight when the desired resolution is a 5 cm pixel size or greater (Oldeland et al, 2017). Pixel with sizes of 2 cm can also be achieved, but only in several flights (Oldeland et al, 2017). To this, drone needs to double the disk space required for storing images (Oldeland et al, 2017).

Moreover, eBee drones have significantly more ground coverage than quadcopters, since affordable quadcopter systems cannot usually cover 1 km^2 in a single flight (Oldeland et al, 2017).

SenseFly eBee Canon IXUS127 HS Digital camera have dimensions of 93.2 mm × 57.0 mm × 20.0 mm and it has a weight of 135 g (Kachamba et al., 2016). The camera produces 16.1-megapixel images in the red, green, and blue spectral bands (Kachamba et al., 2016). The camera automatically set with a shutter speed of 1/2000 seconds (Sense Fly, 2014). The eBee is made from flexible foam and its weight without cameras is 537 g (Kachamba et al., 2016). Acquisition of images of these drones is usually performed from laptop computers with the eMotion software (Kachamba et al., 2016). One of the images generated is an orthophoto which provides visual identification of areas with and without vegetation (Kachamba et al., 2016). It is used to create a Digital Terrain Model (DTM) of the area (Kachamba et al., 2016). It would be used to calculate trees' height relative to the ground (Kachamba et al., 2016). In fact, reliability biomass estimates from remotely sensed three-dimensional data are heavily dependent on the generation of good quality DTMs (Kachamba et al., 2016).

To conclude, it is advantageous to use eBee drones' cameras to estimate forestry biomass. To take this conclusion it was considering that here were only mentioned one camera of eBee drones, that was the first appearing. Since 2009, when Canon IXUS surged in market, cameras have obviously suffered updates and it is appearing new cameras, with more and better functionalities. This fact reinforces the illation about their utility.

9. Carbon Credits

Carbon offsets constitute a way of compensation for emissions by funding an equivalent Carbon Dioxide reduction elsewhere (Ojjeh, 2022). This can occur, for instance, through capture of methane released in landfills or through a reforestation project (Murphy et al., 2013). Besides remote sensing can be used to estimate carbon capture by measuring forests' biomass, it is also useful in identification of eligible lands for reforestation (Kale et al., 2009).

Carbon credits are tradable certificates that represent offsets (Ojjeh, 2022), providing new economic opportunities for farmers and forest growers (Murphy et al., 2013). In fact, they can be voluntary purchased and used by individuals and companies (Murphy et al., 2013).

10. Conclusions

To conclude, remote sensing is useful to estimate forests' biomass considering the advantages of satellites and mainly of drones. However, the satellites errors are still a little high, about 20% in comparison to field measurements. The use of some smartphone applications can also be useful in most difficult locals. It can be used to refine remote sensing measurements and even to compare with it. Nevertheless, other applications need to be improved to permits that to be eventually one of the solutions for conventional forest inventory methods.

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12. Conflicts of interest

The author declared no conflict of interest.

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